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SPECIFICATION

1. Title of the Invention

COLOR LIQUID CRYSTAL DISPLAY DEVICE

2. Scope of Claims

(1) A color liquid crystal display device, which is configured of a liquid crystal layer interposed between a pair of substrates each having electrodes, and a pair of polarizers disposed in a way that the substrates are interposed between the pair of polarizers from outside thereof, and which displays multiple colors by changing an amount of birefringence of the liquid crystal layer by applying a voltage to the electrodes, and thus by controlling birefringence colors which change along with changes in this birefringence, the color liquid crystal display device characterized by comprising a color filter.

(2) The color liquid crystal display device according to claim 1, characterized in that any one of a red color filter and a yellow color filter is provided to each of pixels which do not display a blue color.

(3) The color liquid crystal display device according to claim 1, characterized in that a cyan color filter is provided to each of pixels which do not display a red color, while a yellow color filter is provided to each of pixels which do not display a blue color.

3. Detailed Description of the Invention

[Industrial Applicability]

The present invention relates to a liquid crystal display device of an ECB mode, a DAP mode or the like, which displays multiple colors using birefringence colors of a liquid crystal layer.

[Prior Art and Problems to be Solved by the Invention]

A general color display device using an LCD (liquid crystal device) is provided

with red, green and blue color filters in each of pixels, and reproduces colors by turning on and off each of the colors. The general color display device can produce colors in a wide range by matching a light transmission characteristic of each of the color filters with an optical characteristic and the like of a backlight and a liquid crystal layer. Such an LCD, however, requires three processes to be performed for coloring the color filters. Moreover, unless the light transmission characteristics of the color filters are carefully designed, the range of the color reproduction becomes significantly narrow. Furthermore, such an LCD displays colors by using additive color mixtures of colored lights, which have transmitted through the red, green and blue color filters. Accordingly, each of the pixels can develop only one color among the red, green and blue colors, and thus the pixel density has to become 1/3.

As another conventional color display method, known is a method such as an ECB mode, an HAN mode or a DAP mode, which utilizes birefringence colors of a liquid crystal layer. In this method, an electric field is applied to the liquid crystal layer, and alignment states of liquid crystal molecules are changed. In this way, an amount of birefringence is controlled, and thus the displaying is performed by using the birefringence colors. In this method, it is not necessary to provide color filters to each of the pixels, and a cell configuration and a cell manufacturing process are also significantly simplified.

In a case of the conventional LCD employing the color display method using birefringence colors for displaying colors, however, there are problems such as the following. It is difficult to reproduce a red color with high color purity, since colors of approximately 400 to 450 nm (violet to blue) are mixed thereto in a case of displaying a red color. Moreover, a range of color reproduction is narrow, since only birefringence colors are used (p. 169, J66-C, 1983, "*Journal of Institute of Electronics and Communication Engineers of Japan*"). Furthermore, it is difficult to display a black color when a time-division driving method is used.

The present invention has been made in view of the aforementioned problems in a liquid crystal display device of a type which displays colors by use of birefringence colors. An object of the present invention is to provide a color liquid crystal display device which has excellent display characteristics as follows. It is possible to reproduce a red color with high color purity. A range of color reproduction is wide. It is possible to display a black color. Furthermore, a pixel density is high.

[Means for Solving the Problems and Operation]

In order to achieve the aforementioned object, the present invention provides a color liquid crystal display device, which is configured of a liquid crystal layer interposed between a pair of substrates each having electrodes, and a pair of polarizers disposed in a way that the substrates are interposed between the pair of polarizers from outside thereof, and which displays multiple colors by changing an amount of birefringence of the liquid crystal layer by applying a voltage to the electrodes, and thus by controlling birefringence colors which change along with changes in this birefringence, the color liquid crystal display device being characterized by including a color filter.

Moreover, the present invention provides the color liquid crystal display device of the above described configuration, the device being characterized in that any one of a red color filter and a yellow color filter is provided to each of pixels which do not display a blue color.

Furthermore, the present invention provides the color liquid crystal display device of the above described configuration, the device being characterized in that a cyan color filter is provided to each of pixels which do not display a red color, while a yellow color filter is provided to each of pixels which do not display a blue color.

Hereinafter, descriptions will be given of a color liquid crystal display device of the present invention.

As modes of a liquid crystal display device capable of displaying colors by

using birefringence colors, there are an ECB mode, a DAP mode, an HAN mode and the like. The ECB mode uses a liquid crystal cell in which liquid crystal molecules having a positive dielectric anisotropy are aligned substantially horizontally to substrates. The DAP mode uses a liquid crystal cell in which liquid crystal molecules having a negative dielectric anisotropy are aligned substantially perpendicularly to substrates. The HAN mode uses a combination of the substantially horizontal alignment and the substantially perpendicular alignment on the upper and lower substrates. Today, the situation is, however, that a range of colors, which can be reproduced in any of these modes, is narrow since the color purity of a red color in particular is not high. Furthermore, when using the time-division driving method, it is difficult to display a black color. In Fig. 1, birefringence colors are shown when a horizontally aligned liquid crystal cell is disposed between two polarizing plates arranged in a crossed nicol state so that an alignment direction of the liquid crystal molecules and a transmission axis direction of the polarizing plates would form an angle of 45 degrees. The trajectory shows a manner of a color change when a thickness of a liquid crystal layer is changed. In Fig. 1, the thicknesses of the liquid crystal layer are expressed by using values obtained by calculating $\Delta n \times d$ (by microns), which is a product of a thickness of the liquid crystal layer d and a refractive index anisotropy of the liquid crystal Δn . The data shown in Fig. 1 corresponds to an LCD of the ECB mode. Although colors are displayed in an actual cell by applying an electrical field to the liquid crystal layer, and by thus changing an amount of birefringence of the liquid crystal layer, here, this change in an amount of birefringence is replaced with a change in the thickness of the liquid crystal layer. In Fig. 1, R, G and B, respectively, denote the three primary colors in NTSC, that is, red, green and blue. On xy coordinates as shown in Fig. 1, it seems that the color purity of blue is high, and that both of the color purity of green and the color purity of red are notably low. When visually observing the colors actually, however, the color purity of green is high, and only the color purity of red is low. This is because the xy

color coordinates system does not reflect actual color senses well. When the data is plotted on the 1960 UCS chromaticity diagram as shown in Fig. 2, it is understood that the colors, except for the red color, are close to the three primary colors. Although the trajectory of the color changes a little by a wavelength dispersion of Δn of the liquid crystal material, the trajectory does not come significantly close to the direction of R, (p. 169, J66-C, 1983, "*Journal of Institute of Electronics and Communication Engineers of Japan*"). This can be understood by observing the dependability of a transmission spectrum on values found by $\Delta n \times d$ (refer to Fig. 3). When $\Delta n \times d$ equals to 0.4 micron or so, the spectrum is too broad, so that it is not possible to allow the wavelength range of only a red color (approximately not less than 620 nm) to transmit. On the other hand, when $\Delta n \times d$ equals to 0.1 micron or so, a transmission peak appears in a blue color range, since an interval between peaks becomes too narrow. In comparison with the facts that only a blue color (400 nm to 500 nm) transmits when $\Delta n \times d$ equals to approximately 0.6 micron, and that only a green color (500 nm to 600 nm) transmits when $\Delta n \times d$ equals to approximately 0.8 micron, it can be understood that it is impossible to reproduce a red color with high color purity with only birefringence colors from these facts.

With this respect, in the present invention, the aforementioned problems are resolved by providing a color filter to an LCD of a type which displays colors by using birefringence colors. Specifically, any one of a red color filter and a yellow color filter is used for each of pixels, which do not display a blue color, for example. When using the red color filter, the visible light whose wavelength is shorter than a range of 500 nm to 600 nm is cut. Thus, it is possible to remove colors (violet to blue) of approximately 400 nm to 450 nm wavelength, which are mixed with a red color in a case where a red color is displayed by use of only birefringence colors. Accordingly, a red color with high color purity can be obtained, and it is made possible to broaden the range of the color reproduction. Moreover, in this case, color filters can be produced in one process,

and thus the process can be significantly simplified in comparison with the color display method using conventional color filters, which requires at least three processes. When using a yellow color filter, the visible light whose wavelength is shorter than 490 nm is cut. Accordingly, it is possible to obtain an effect which is similar to the effect in the case where the red color filter is used. In addition, there are advantages as follows. Specifically, the light whose wavelength is longer than approximately 500 nm can transmit through the pixel provided with the yellow color filter. Accordingly, this results in the following. Descriptions are made for the case of Fig. 3 as an example. When a retardation value of the liquid crystal layer corresponds to 0.7 to 0.8 micron, a green color is displayed. When it corresponds to approximately 0.9 micron, a yellow color is displayed. When it corresponds to approximately 1.0 to 1.2 micron, a red color is displayed. When it corresponds to approximately 0.6 micron, a black color is displayed. Accordingly, as in the manner described above, it is possible to display black, green, yellow and red colors by use of only the pixel provided with the yellow color filter.

In Fig. 4, an example of a transmission spectrum of the above described color filter is shown. An example shown in Fig. 4A, although there is a little transmission in a wavelength range of 400 nm to 450 nm, this transmission does not lead to a major degradation of the characteristic. Many types of materials, which constitute such a color filter, are available. It is easy to employ a material which does not allow light in the blue color range to transmit at all. The chromaticity, at the time when using a color filter having the characteristic shown by (a) in Fig. 4, is indicated with a dot pointed by an arrow in Fig. 2. From this drawing, it is understood that it is possible to reproduce colors including a color, which is very close to a red color point R in NTSC, by use of such a color filter described above.

Furthermore, in the present invention, it is possible to use a cyan color filter for each of pixels which do not display a red color, and to use a yellow color filter for each

of pixels which do not display a blue color.

In the case of combining the color filters as described above, it is possible to obtain an effect, which is similar to the effect of the above described case, by the yellow color filter. Moreover, it is possible to obtain the following operation effect by the cyan color filter.

In Fig. 5, an example of a transmission spectrum of the cyan color filter is shown together with an example of a transmission spectrum of the yellow color filter. A pixel provided with the cyan color filter allows the light of 400 nm to 570 nm to transmit. Accordingly, this results in the following. Descriptions are made by use of Fig. 3 as in the above described case. When a retardation value of the liquid crystal layer is 0.55 micron, a blue color is displayed. When it is 0.7 micron, a cyan color is displayed. When it is 0.8 micron, a green color is displayed. When it is 0.45 micron, a black color is displayed. Thus, it is possible to further broaden the range of color reproduction.

[Example]

Hereinafter, examples of the present invention will be described. The present invention, however, is not limited to these examples.

(Example 1)

A vertical alignment agent FC-805 manufactured by 3M Company was applied by using a spinner to a surface of a glass substrate, on which transparent electrodes have been patterned. The substrate was then baked for one hour in an oven at 130 °C. Next, the surface to which the alignment agent has been applied was rubbed with a non-woven fabric. A red filter having the characteristic (a) shown in Fig. 4 was printed on only parts of another substrate, the parts corresponding to red pixels. Subsequently, the same alignment process as the one described above was performed. A cell was formed by adhering the substrate with the filter and the substrate without a filter to each other in a way that rubbing directions of the substrates are antiparallel to each other. The

thickness of the cell was controlled by dispersing glass fibers having an average diameter of 10.0 microns on the substrates. ZLI-3640, which is nematic liquid crystals having dielectric anisotropy, and which is manufactured by MELC Co., ltd, was filled in this cell.

When the cell filled with the liquid crystals was observed by use of a polarization microscope, it was confirmed that liquid crystal molecules were approximately vertically aligned and tilted to the rubbing direction by approximately 1 degree.

Then, an LCD was formed by disposing this cell between two polarizing plates, which are arranged in a crossed nicol state, in a way that the transmission axis and the rubbing direction of the cell form an angle of 45 degree. A voltage was applied to the electrodes of this LCD, and then the colors of this cell were observed. As a result, when the voltage was sufficiently low, all the pixels were black, but when applying a voltage little by little, all the pixels were turned on. The pixels having the red color filter became red, and the other pixels became white. When the voltage was further increased, the pixels having the red color filter remained red, and the other pixels gradually changed from yellow to pink. When a further higher voltage was applied, the pixels having the red color filter gradually became dark and then black, and the other pixels changed from violet to blue to green. The manners of these changes are shown in Table 1.

TABLE 1

	small		large	
	0	->	voltage	->
pixels having red color filter	black	->	red	-> black

other pixels	black -> white -> yellow -> pink -> violet -> blue -> green
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By use of all the voltage regions used in this example, the pixels having the red color filter became black and red, and the other pixels became black and colors in the range of all the chromaticities represented in Fig. 2. Accordingly, the color range obtained by mixing these colors was significantly broadened.

(Example 2)

A cell was made in a similar manner to that of Example 1, by use of a horizontal alignment agent HL-1100 manufactured by Hitachi Chemical Co., Ltd. as an alignment agent. ZLI-2293, which is liquid crystals having a positive dielectric anisotropy, and which is manufactured by MELC Co., Ltd., was filled in the cell, and thus an EGB mode cell was made. The thickness of the cell was set at approximately 8 microns. This cell was interposed between two polarizing plates arranged in a crossed nicol state, in a way that the rubbing direction and the transmission direction form an angle of 45 degrees. Then, operations of the cell were observed. As a result, in this case, when no voltage is applied, the pixels having the red color filter were red, and the other pixels were red-purple. Then, when a voltage was applied, the colors of the pixels having the red color filter changed from red to black, and the other pixels changed from pink to yellow to green. When a voltage was further applied, the pixels having the red color filter lighted again and became red, but the other pixels changed from blue to red-purple to pink to yellow to white. The manners of these changes are shown in Table 2.

TABLE 2

voltage	0	->	medium	->	large
pixels having red color filter	red	->	black	->	red

other pixels	red-purple -> pink -> yellow -> green -> blue -> pink -> yellow -> white
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When a sufficiently higher voltage was applied, all of the pixels gradually became dark. The range of the color reproduction was significantly broadened to the same degree as that of Example 1.

(Example 3)

An LCD was manufactured by use of a yellow color filter having the characteristic shown by (b) in Fig. 4, instead of the red color filter in Examples 1 and 2. The pixels, which are provided with the yellow filter, became capable of displaying colors in the range of orange, yellow, yellowish green and green, in addition to red.

(Example 4)

A liquid crystal cell was made in the similar manner to that of Example 1 except that a red color filter was not printed. Then, the same liquid crystals as those of Example 1 were filled therein. The cell in which the liquid crystals have been filled was disposed between two polarizing plates arranged in a crossed nicol state, in a way that the transmission axis of the polarizing plates and the rubbing direction of the substrate form an angle of 45 degrees. Then, by applying a voltage to the electrodes, birefringence colors were generated, and a voltage, which makes the colors green to red colors, was searched for. Next, a color glass filter V-Y50 (whose transmission spectrum is approximately the same as that of the yellow color filter in Fig. 5) manufactured by Toshiba Corporation was superposed thereon. Then, when the voltage was increased and reduced a little, the color changed from black to green to yellow to red. When an experiment was performed in a similar manner using a cyan color filter, it was confirmed that desired effects can be obtained. Then, a color liquid crystal display device using these two color filters, the aforementioned crystal liquid cell and the polarizing plates, was defined as the color liquid crystal display device of the present invention.

(Example 5)

A liquid crystal cell was made by use of a horizontal alignment agent HL-1100 manufactured by Hitachi Chemical Co., Ltd. as an alignment agent in a similar manner to that of Example 4. ZLI-2293, which is nematic liquid crystals having a positive dielectric anisotropy, and which is manufactured by MELC Co., Ltd., was filled in the cell. Thus, an LCD of EGB mode was made. Then, this liquid crystal device was interposed between polarizing plates arranged in a crossed nicol state, and birefringence colors were generated by applying a voltage to electrodes. Subsequently, an experiment was performed using a yellow color filter and a cyan color filter in a similar manner to that of Example 4, and the effects of the invention were confirmed as in the case of Example 4. Then, a color liquid crystal display device using these two color filters, the aforementioned cell and the polarizing plates, is defined as the color liquid crystal display device of the present invention.

[Effects of the Invention]

According to the color liquid crystal display device of the present invention, the following effects can be obtained because birefringence colors, which change along with changes of retardation of the liquid crystal layer, and color filters are used.

(1) It is made possible to reproduce a red color with high color purity, and to display a black color, which have been impossible to be reproduced by the conventional color liquid crystal display device using birefringence colors only, and thus, the displaying of multiple colors in a wide range of color reproduction can be performed.

(2) An image density is improved.

(3) A manufacturing process of a color filter can be shortened, and a cell configuration is simplified, in comparison with the case of the conventional color liquid crystal display device using color filters.

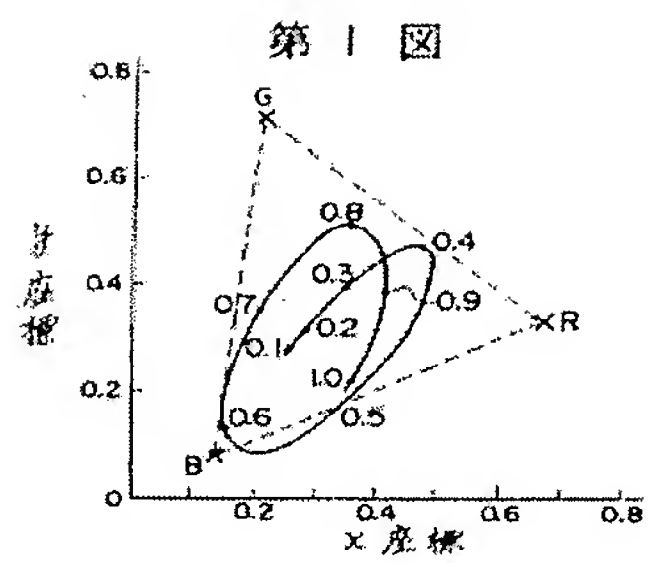
4. Brief Description of the Drawings

Fig. 1 is a graph showing birefringence colors obtained when a horizontally aligned liquid crystal cell is disposed between two polarizing plates arranged in a crossed nicol state, in a way that an alignment direction of liquid molecules and a transmission axis direction of the polarizing plates form an angle of 45 degrees; Fig. 2 is a graph in which data in Fig. 1 is plotted on the 1960 UCS chromaticity diagram; Fig. 3 is a graph showing dependability of a transmission spectrum on values obtained by calculating $\Delta n \times d$; Fig. 4 is a graph showing examples of transmission spectra respectively of a red color filter and a yellow color filter, which are used in the present invention; and Fig. 5 is a graph showing examples of transmission spectra respectively of a cyan color filter and a yellow color filter, which are used in the present invention.

Patent Applicant; Ricoh Company, Ltd.

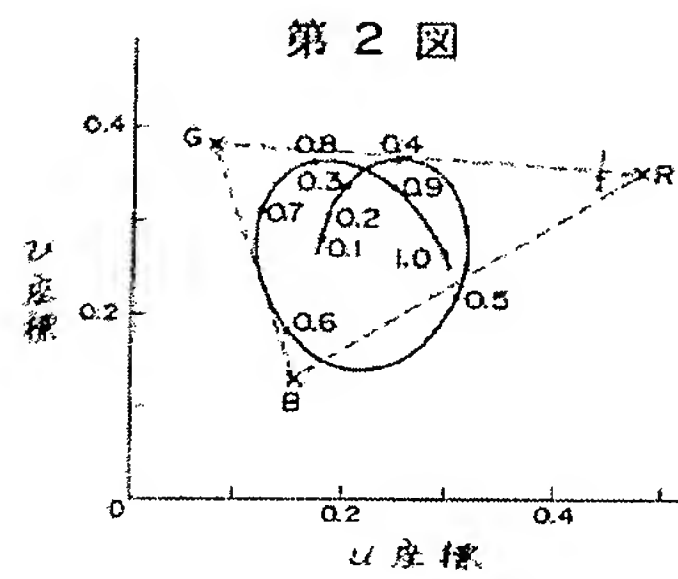
Representative: Patent Attorney; Toshiaki Ikeura (and another)

FIG. 1



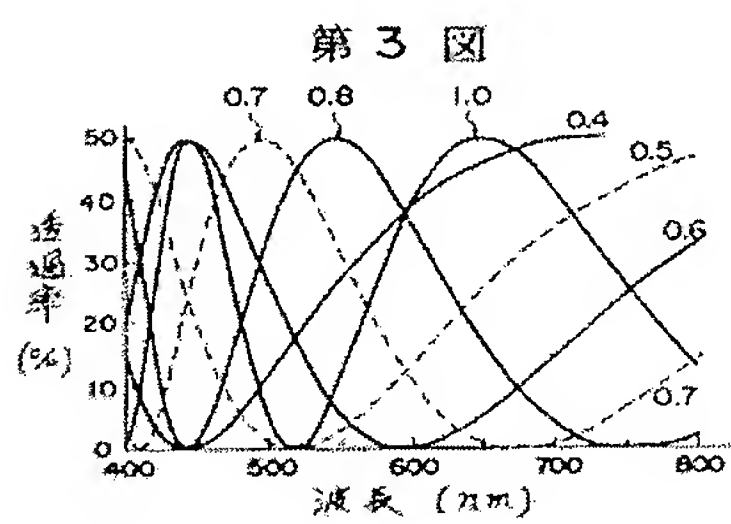
Y COORDINATE AXIS
X COORDINATE AXIS

FIG. 2



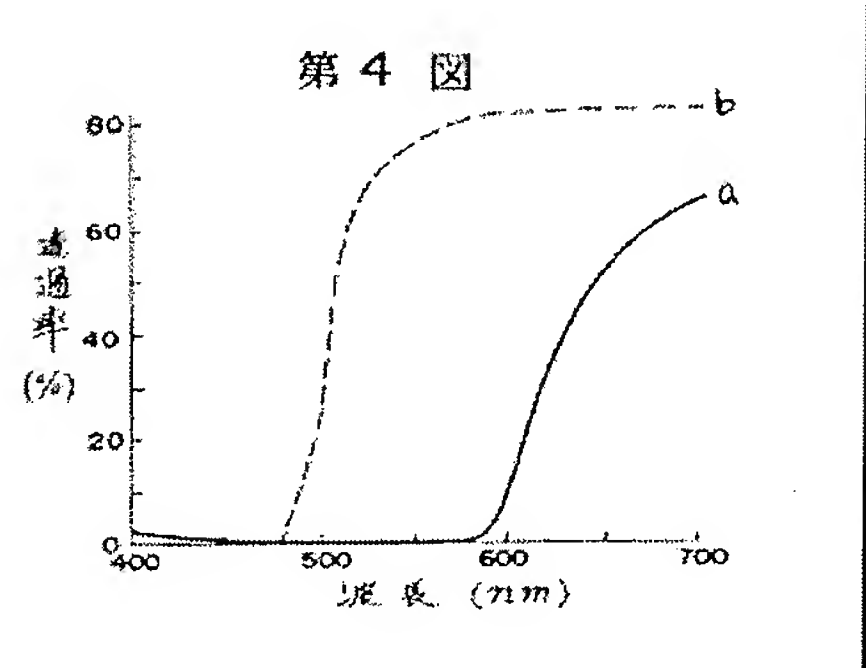
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FIG. 3



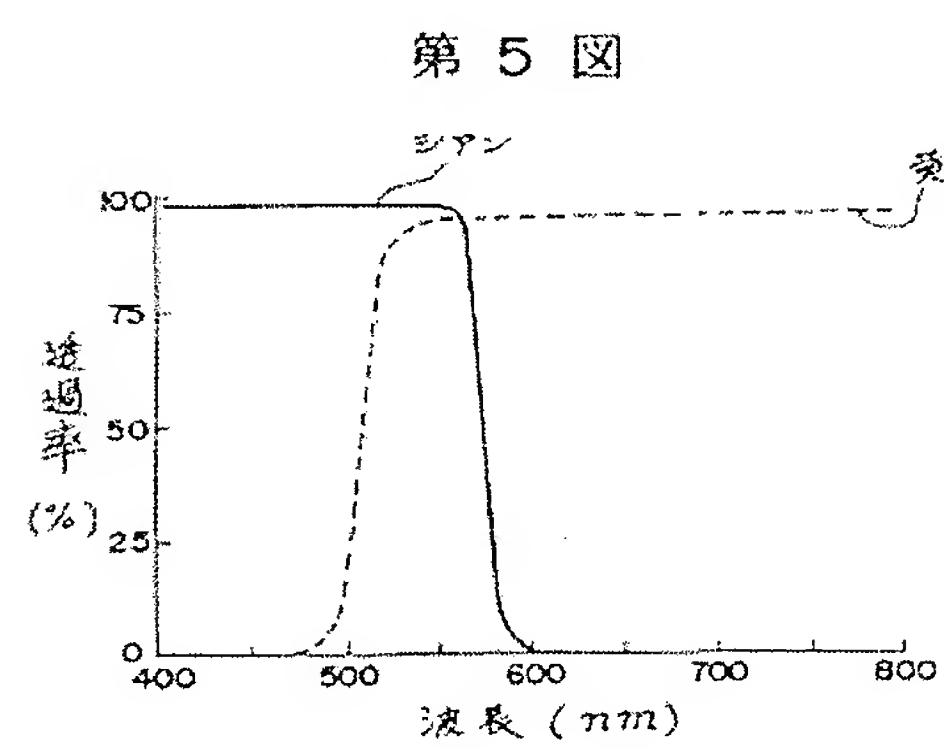
TRANSMISSIVITY (%)
WAVELENGTH (nm)

FIG. 4



TRANSMISSIVITY (%)
WAVELENGTH (nm)

FIG. 5



TRANSMISSIVITY (%)
WAVELENGTH (nm)
CYAN
YELLOW